A Multiscale Study of Tropical Cyclone Formation, Structure Change, and Predictability in the Western North Pacific Region and TCS08 Experiment Support

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LONG-TERM GOALS AND OBJECTIVES

The overarching objectives of this research project are to obtain an improved understanding of the formation, predictability and structure change of tropical cyclones in the Western Pacific region. During the first year of this project fruitful applied research has been completed in support of the Tropicala Cyclone Structure 2008 (TCS08) field campaign. Due to space limitations, only one of our ongoing research projects on TCS08 will be summarized here.

- ## Tropical Cyclogenesis of Typhoon Nuri Within an Easterly Wave Critical Layer?

APPROACH

In recent work the P.I. and two of his collaborators have outlined a new paradigm of tropical cyclogenesis that occurs within the critical layer of easterly waves for the Atlantic and East Pacific Basins (Dunkerton, Montgomery & Wang 2008). This 'Marsupial Paradigm' and is focused on three key hypotheses:

H1: The intersection of the wave trough and critical layer is the favored region for genesis and a region of strong curvature vorticity/weak shearing deformation.

H2: The critical layer provides a protective environment or 'pouch' that shields the embryonic sub-synoptic-scale vortex from the external hostile environment (i.e. vertical wind shear and intrusion of dry air) and is a favored region for repeated moistening by convection. Once the proto-vortex matures, it emerges from the parent wave as an independent and self-sustaining entity.

H3: The parent wave is maintained and possibly enhanced by diabatically amplified eddies within the wave (proto-vortices on the mesoscale), a process favored in regions of small intrinsic phase speed.

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14. ABSTRACT
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For the TCS08 field experiment, we have hypothesized that the 'Marsupial Paradigm' is operative in the Western Pacific sector and that easterly waves are a more common formation mechanism than generally believed. Our initial analysis of typhoon Nuri (summarized below) suggests that the paradigm and these types of analyses can indeed be applied to the Western Pacific and provide useful forecast guidance to U.S. Naval operations in this region.

WORK COMPLETED / RESULTS

Wave Tracking

The precursor for typhoon Nuri was an easterly wave originating in the Central Pacific that we were able to track in observational data for 10+ days prior to JTWC declaring Nuri a tropical storm (see Figure 1). Wang, Montgomery, and Dunkerton (2008) developed a forecast methodology using operational forecast models to predict 'pouch' evolution and the preferred region for tropical cyclone genesis in real time. These forecasts were produced daily during TCS08 using three global models by the following steps: 1) Calculate the phase speed of the parent wave. 2) Develop translating streamline analysis (similar to a storm relative motion). 3) Identify the intersection of the wave trough axis ($v = 0$) and critical layer ($u = C_p$). 4) Create forecasts diagnostics for a 3x3 degree box centered on this point. These diagnostics are considered an approximate representation of conditions within the 'pouch'. The success of these forecasts in an operational environment was evident during the 15 Aug Daily Planning Meeting as the T+60 hr NOGAPS 'Marsupial Forecast' accurately predicted typhoon Nuri's eventual genesis location, while the global models maintained an open wave and failed to predict formation. These forecasts were critical in the decision to fly the storm and demonstrate the potential for use of this methodology in real time Naval operations.

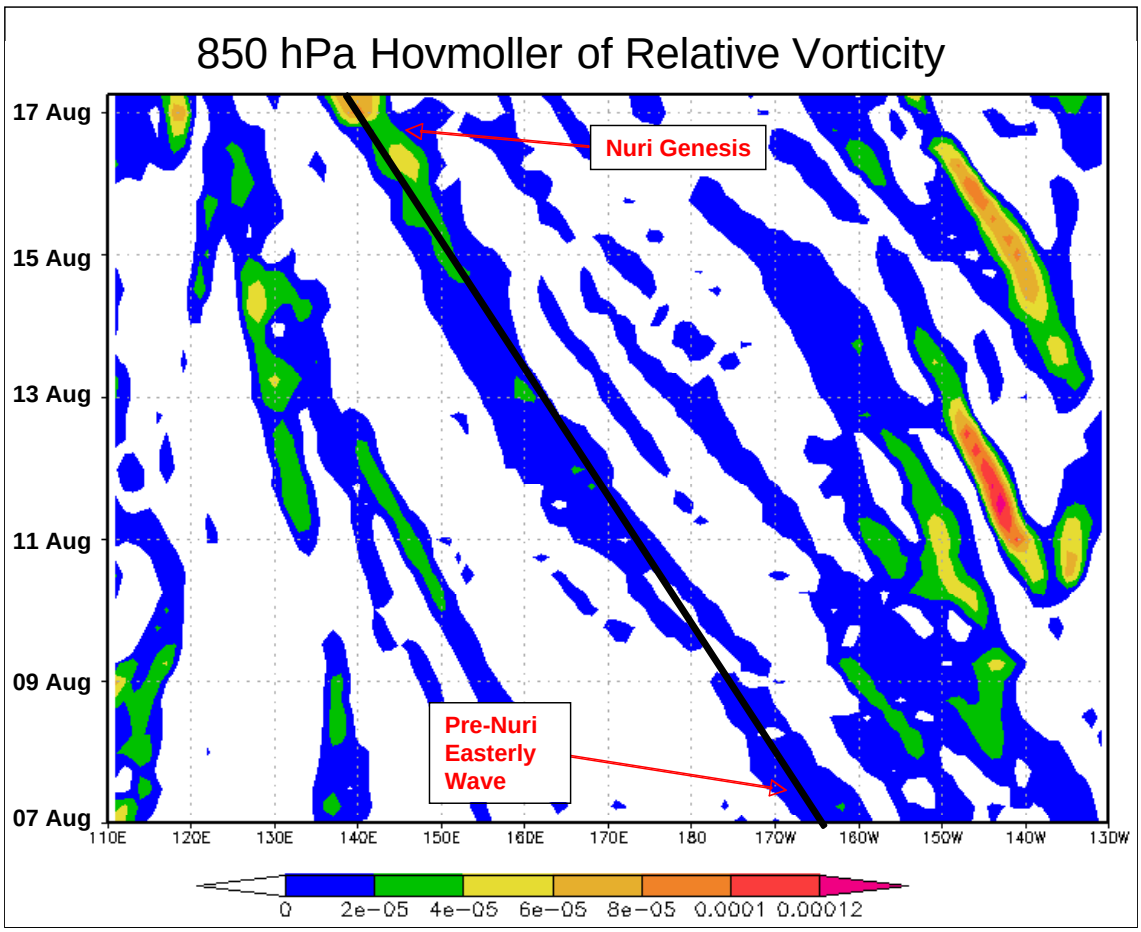

Figure 1. Hovmoller of relative vorticity averaged over 8-18N from 7-17 August 2008. The figure depicts a coherent wave signal (e.g. the pre-Nuri disturbance) that can be tracked for 10+ days prior to tropical cyclogenesis.

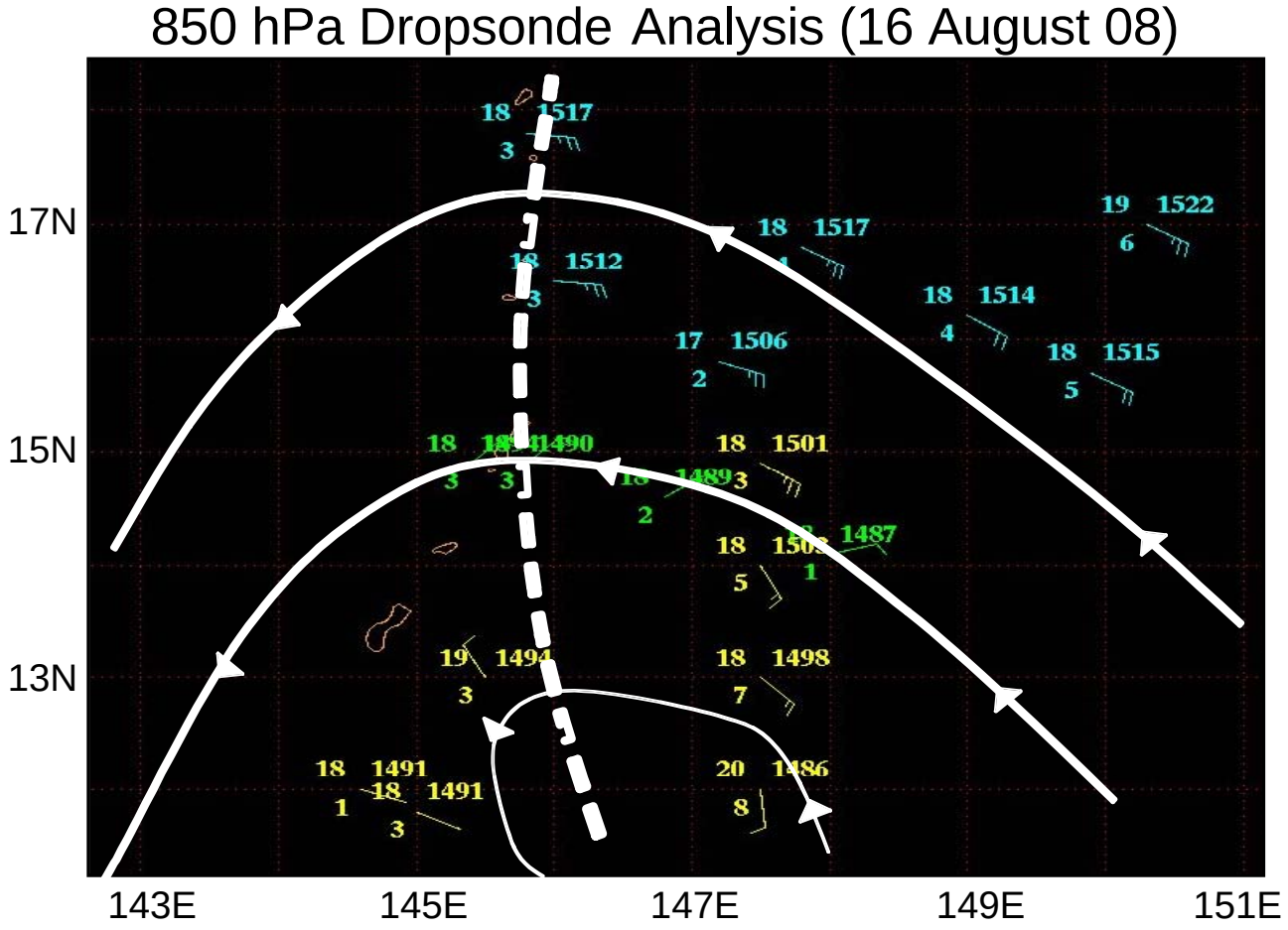

Figure 2. C-130 and NRL P3 dropsonde observations and streamline analysis at 850 hPa confirms the existence of the pre-Nuri easterly wave on 16 August 2008.

As the system moved closer to Guam, USAF C130 dropsonde data confirmed the existence of an easterly wave on 16 Aug. In the resting frame, the closed circulation appears further south than in the translating frame (see Figure 2). When viewed in the translating frame of reference (moving with the zonal phase speed of the wave), a closed circulation is clearly evident on 12Z 15 August (see Figure 3). The marsupial theory hypothesizes that deep convection is reinvigorated and persistent within the pouch region.

The second C130 flight identified a broad mesoscale circulation center at 850 hPa in the southwestern portion of the flight track at approximately 14N, 139.5E (not shown). This circulation center appeared to tilt with height and was very weak and shallow. The area where this broad circulation was observed was concurrent with the area of strongest convection and fairly consistent with the closed low-level circulation in the GFS FNL resting frame analysis. DMW08 and WMD08 both note the presence of short-lived mesoscale circulations within the "pouch", and it is believed that this circulation is of that type.

It is shown in our formal publication that the tropical cyclone forms at the location of the "sweet spot", supporting the hypothesis that this weak mesoscale circulation was not the persistent, robust low-level circulation that eventually became Typhoon Nuri. It is also shown that the critical layer/wave trough

intersection proves to be the center of the tropical storm circulation, as predicted by the marsupial theory.

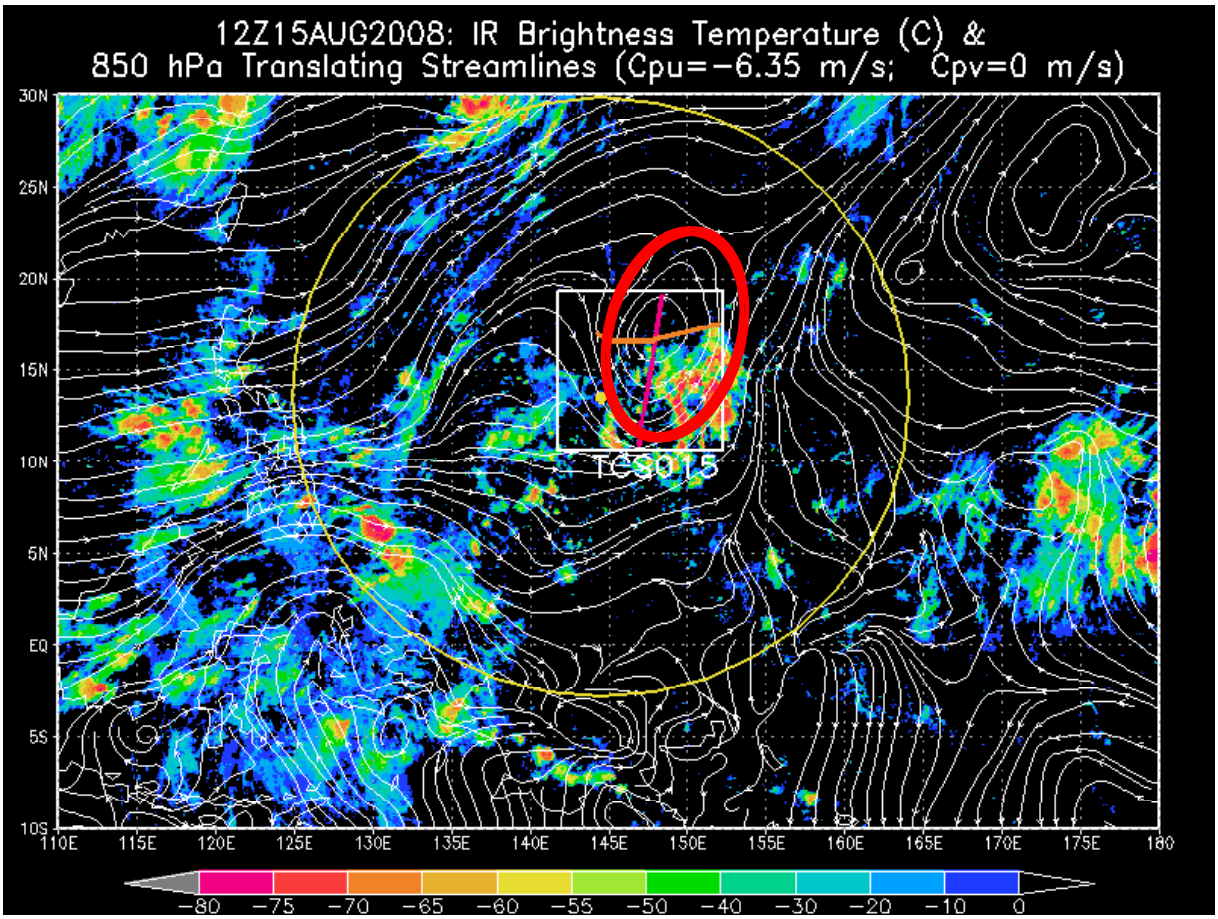

Figure 3. IR Brightness Temperature and GFS 850 hPa translating streamlines for pre-Nuri easterly wave on 12 UTC 16 August 2008. The 'sweet spot' is represented by the intersection of the magenta and gold lines and the red oval approximates the 'pouch'. Although convection is most vigorous to the southeast of the 'sweet spot' it remains in the 'pouch' supporting the applicability of the aforementioned hypotheses to the western Pacific sector.

IMPACT / APPLICATIONS

The impact of this work is clear. It suggests that the 'Marsupial Paradigm' can be used to improve Naval Weather Forecasts in the western Pacific region in cases in which an easterly wave disturbance can be tracked in observations and models. Our immediate next steps are to analyze C-130 and NRL P3 Eldora data to evaluate the mesoscale processes occurring within the 'mother pouch' during the genesis sequence of Nuri. We will in particular use these analyses to assess the existence and role of Vortical Hot Towers (VHTs) in the tropical cyclogenesis process (Hendricks et al. 2004, Montgomery et al. 2006).

TRANSITIONS / FUTURE WORK

A formal publication of the above work is under preparation and will soon be submitted for peer review. A second formal publication is also planned to document the mesoscale processes within the

'mother pouch' of pre-typhoon Nuri. Several other genesis cases were observed during the TCS08 field campaign and these will be analyzed thoroughly as well as part of this research project. Finally, the secondary eyewall formation observed in typhoon Sinlaku will be analyzed as part of the tropical cyclone structure change component of this research project.

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PUBLICATIONS COMPLETED UNDER SUPPORT OF THIS GRANT

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Wang, Z., **M. T. Montgomery**, and T. J. Dunkerton, 2008: A dynamically-based method for forecasting tropical cyclogenesis location in the Atlantic sector using global model products. *Geophysical Research Letters*, [refereed, in review].

AWARDS

2008 Naval Postgraduate School, Graduate School of Engineering and Applied Sciences (GSEAS) Merit Award for Research: "For his fundamental contributions to the understanding of tropical cyclones, their formation, dynamics and prediction, and for his dedication to the mentoring of graduate students and young scientists in a collaborative environment"

2003 American Meteorological Society Clarence Leroy Meisinger Award for “Providing fundamental understanding in asymmetric hurricane dynamics and vortex Rossby waves”

1998 Colorado State University, Engineering Faculty Award of Excellence for “Outstanding achievements and professionalism in education and service to the Atmospheric Science Program”